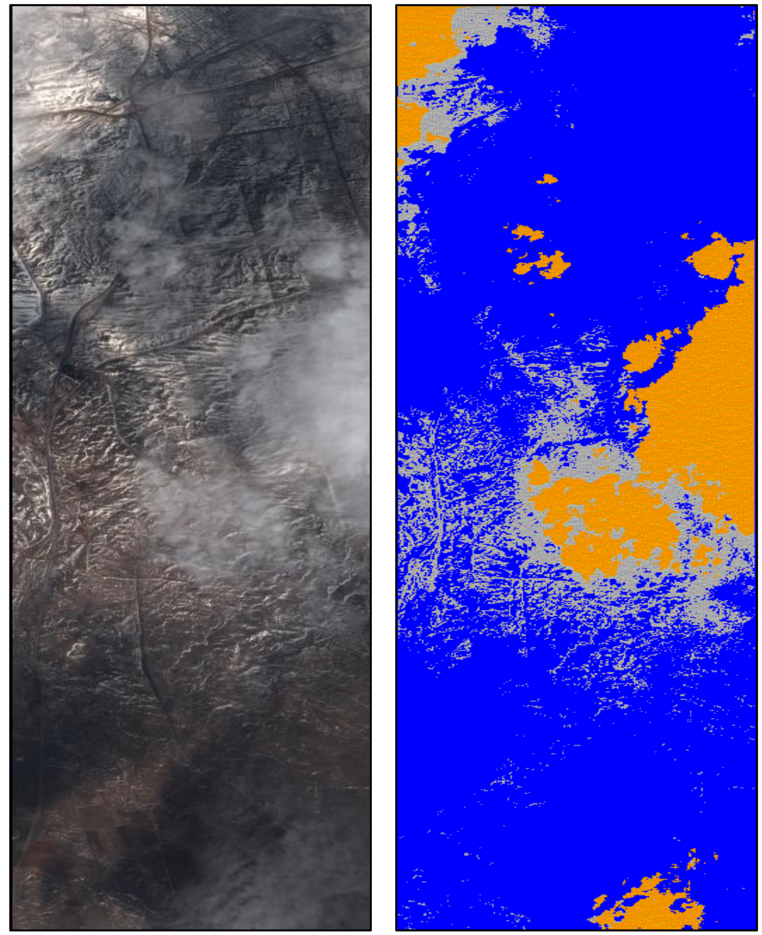
EO1Onboard Cloud Cover Detection Validation Preliminary Report



March 11, 2003

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Agenda

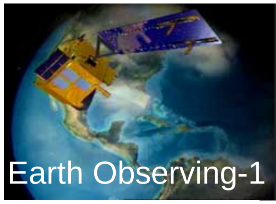
- *Introduction – Dan Mandl & Jerry Miller*
- *Requirements – Dan Mandl*
- *Development Effort – Bruce Trout*
- ***Cloud Assessment Procedure – Michael Griffin***
- ***Conclusion – Jerry Miller & Dan Mandl***

Intro: Cloud Cover Assessment Concept

- *Rationale: On board cloud assessment has the potential to considerably reduce the resources on downlink for unwanted scenes.*
- *Concept: Flight validate an onboard cloud cover detection algorithm and determine the performance that is achieved on the Mongoose V*
- *Approach:*
  - ***Formulate and test a cloud cover determination algorithm that is compatible with Hyperion sensor measurements***
  - ***Using MIT / LL provided algorithm, implement and test code to execute on EO-1 platform***
  - ***Uplink and execute code updates onboard EO-1, and evaluate its performance on orbit***
- ***TRL In = 5*** ***TRL Out = 6***

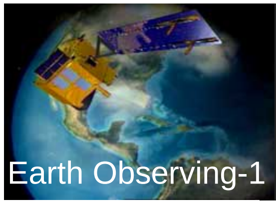
Intro: Initial Results

- *Final onboard cloud cover assessment of an EO-1 8 second (.75 Gbyte) Hyperion scene was expected to take hours but instead took less than 30 minutes*
- *Streamlined algorithm by:*
  - ***Performing level 0 on all data and then selecting the needed 6 bands***
  - ***Converted level 0 data to radiance (level 1R) one scan line (256 pixels) at a time***
  - ***Performed pixel by pixel cloud assessment***
- *Can perform onboard cloud assessment faster with the following capabilities:*
  - ***Subsampling of raw data (can get close to same results without processing all data)***
  - ***User defined area of interest within image and only process that portion***
  - ***Direct access to science recorder***
  - ***Cloud assessment algorithm can be expanded since we had more margin than expected***
- ***For 20 test cases on ground, performed cloud assessment within 5% for major test cases***



Intro: Comparison of ESTO On-board Cloud Cover Studies

	1999	*2002/2003*
Test type	*Simulation*	*On-orbit*
Instrument	*NOAA14 AVHRR multispectral*	*EO-1 Hyperion hyperspectral*
Bands	*.58-.68-.725-1.10-3.55-3.93-10.3-11.3-11.5-12.5*	*.55-.66-.86-1.25-1.38-1.65*
Processing scenario	*Real time*	*About 1 orbit*
Processor	*Commercial Power PC 750, 233 Mhz, 450 MIPS*	*Rad hard Mongoose V, 12 Mhz, 6-7 MIPS*
Operating System	*Linux*	*VxWorks*
Software Preprocessing	*Albedo, radiance and brightness test*	*Raw data>> L0 >>Level 1b >> reflectance*
Tetsed algorithms	*Land, sea, day, night, clouds, ice, snow, sand, sun glint*	*Differentiate clouds from ice, snow, sand and water*



Intro: Spacecraft

- ***Two primary Science Instruments***
  - ***Advanced Land Imager***
    - *10m resolution*
    - *Visible imager*
    - *Questionable if can access data onboard due to onboard format*
  - ***Hyperion***
    - *30m resolution*
    - *Hyper spectral imager (220 bands)*
    - *Data access onboard for cloud detection*
  - ***Orbit***
    - *705 km Altitude*
    - *~15 day Repeat track*
    - *98.7 degree inclination*

Earth Observing-1

Intro: EO-1 Extended Mission Testbed Activities

Onboard Processing

① Onboard Cloud Cover Detection Validation

$180K

Hyperspectral Compression WG

- Onboard data mining
- Onboard intelligent image compression
- Working group

End-to-End Communications

② Preliminary EO-1 Autonomy Experiment

- Onboard planning
- Onboard feature detection
- Dynamic SW Bus

$720K

⑥ Smart Antenna

- Ground phased array
- Cell tower com to sat

AIST ESTO NRA Proposal

Autonomous Coordination

Sensorweb Simulator

- Related activity but not spawned by EO-1
- M. Seablom

$200K

③ Dynamic Resource Management

- Autonomous scheduling of Ground Station by satellite

AIST ESTO NRA Proposal

Operational Testbed

Autonomous Science Experiment(ASE)

- Migration of ST6 onto EO-1

$ TBS

⑤ EO-1, Terra, Aqua Sensorweb Demo

- Uses MODIS inst center to detect volcanoes
- Uses ASE to coord image collect autonomously

no additional funding needed

EO-1/ Gnd Sensor Sensorweb

- Sensors in Huntington Botanical Garden trigger ④ EO-1 image

no additional funding needed

Intelligent Distributed Spacecraft Technology Testbed: NMP (JPL)

Related activity

Funded by ESTO

Funded by NMP

Proposed activity

Note: Numbered boxes are detailed in following slides.

Earth Observing-1

Intro: EO-1 Onboard Cloud Cover Detection With Onboard Replanning

① Funded by ESTO

Calculate cloud score onboard (L0, L1 + cloud alg)

If Score < N

No

Downlink as planned to 1st GS

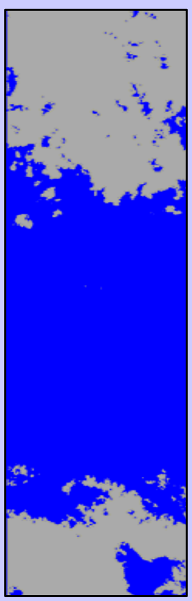
Yes

② Funded by NMP

Replan alternate image onboard and reschedule S/C activities to accomplish new image

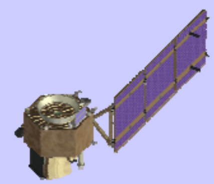
③ Proposed to AIST ESTO NRA

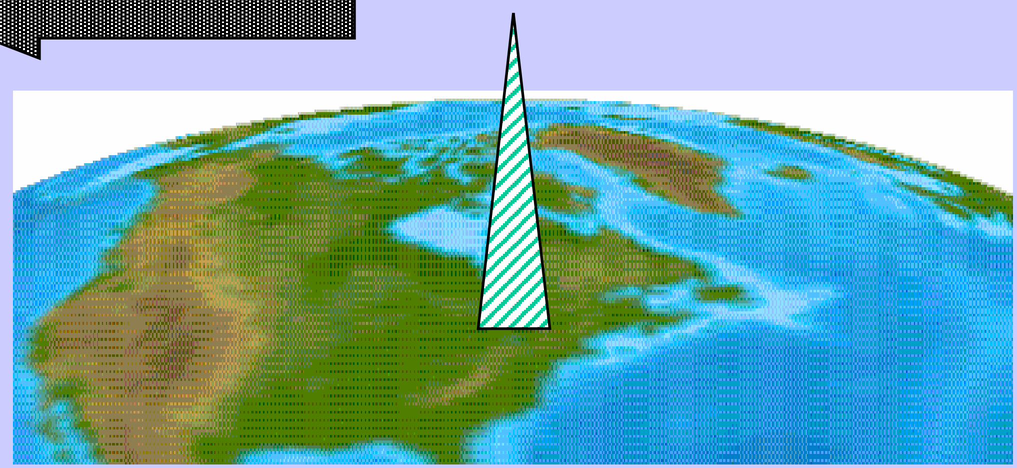
Message GS to cancel old downlink and schedule new contact & receive confirmation

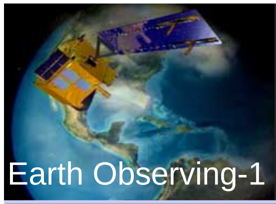


Screen for clouds onboard

Take Image





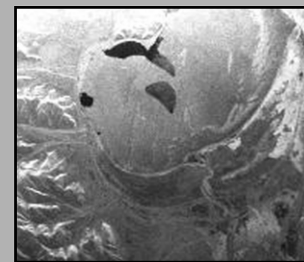


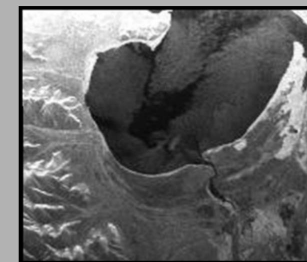
Intro: Related Ongoing Feature Detection Efforts

② **Funded by NMP**

Autonomous Change Detection

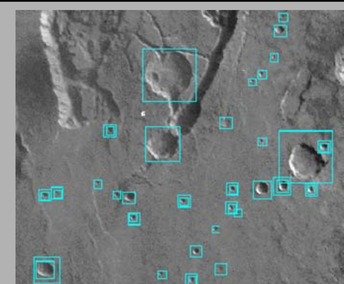
- *Ice formation/retreat, flooding*
- *Atmospheric Change*
- *Volcanic processes (Lava, mud, plume)*





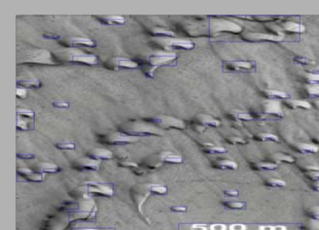
Autonomous Feature Identification

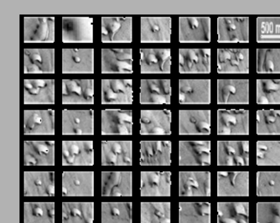
- *Volcanic cinder cones and craters*
- *Impact craters*
- *Sand dunes*



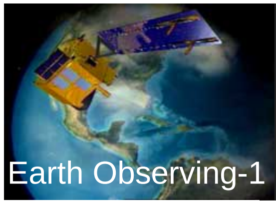
Autonomous Discovery

- Identify features which differ from the background





- Downlink science products: science events, features - not raw data
- Achieves 2x-100's x data reduction!



Cloud Cover Assessment Top Level Requirements

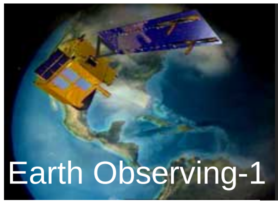
- ***Implement, test, and upload WARP flight software update to perform cloud cover processing on Hyperion SWIR / VNIR image files as requested***
- ***Extract pixel read out values from these files for bands designated for cloud cover assessment use. (Includes both SWIR / VNIR bands)***
- ***Perform radiometric calibration to Level***
- ***Perform cloud cover assessment and telemeter results to the ground***
- ***Provide mechanisms to control cloud cover processing and provide reporting of cloud cover processing status***

Level 0 and Level 1Processing Requirements

- ***Perform playback of requested SWIR / VNIR image data files stored on WARP***
- ***Synchronize on header for 1st science data packet***
- ***Extract each spatial pixel read out value from this packet for bands designated for cloud cover assessment use***
  - ***VNIR bands - 0.55 (band 20), 0.66 (band 31), 0.86 (band 51)***
  - ***SWIR bands – 1.25 (band 110), 1.38 (band 123), 1.65 (band 150)***
  - ***Read out value extraction involves stripping 12 least significant bits of 2 byte value***
- ***Apply level 1 calibration to each level 0 data sample***

Cloud Cover Detection Requirements

- ***Perform pixel by pixel testing using reflectance data to determine which pixels are cloud covered.***
- ***Cloud coverage for a given pixel will be determined based on results of a series of tests as described in the MIT presentation. Types of tests will include:***
  - ***Reflectance Threshold tests. Tests reflectance value for a given spectral pixel relative to a predefined threshold.***
  - ***Ratio test. Tests ratio of reflectance values for 2 different bands for a given pixel relative to a predefined threshold.***
  - ***Normalized Difference Snow Index (NDSI) test. Tests differences of 2 bands divided by sum of the 2 bands relative to a predefined threshold value.***
  - ***Combo test. Uses results of NDSI and Reflectance threshold tests.***
- ***Statistics to be provided which provide total tested and cloudy pixels, and percentage cloudy.***

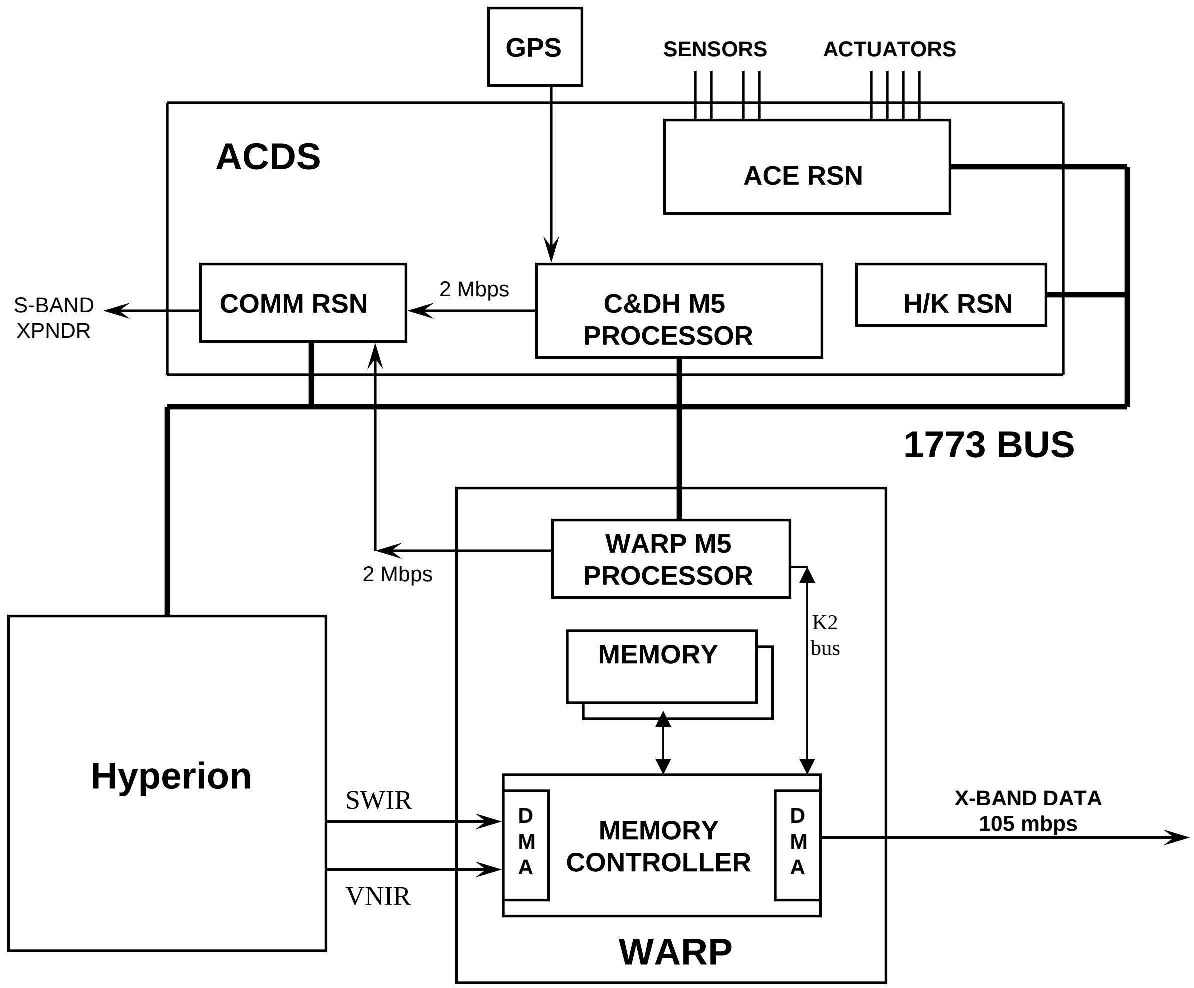


Dev Effort – SW Environment

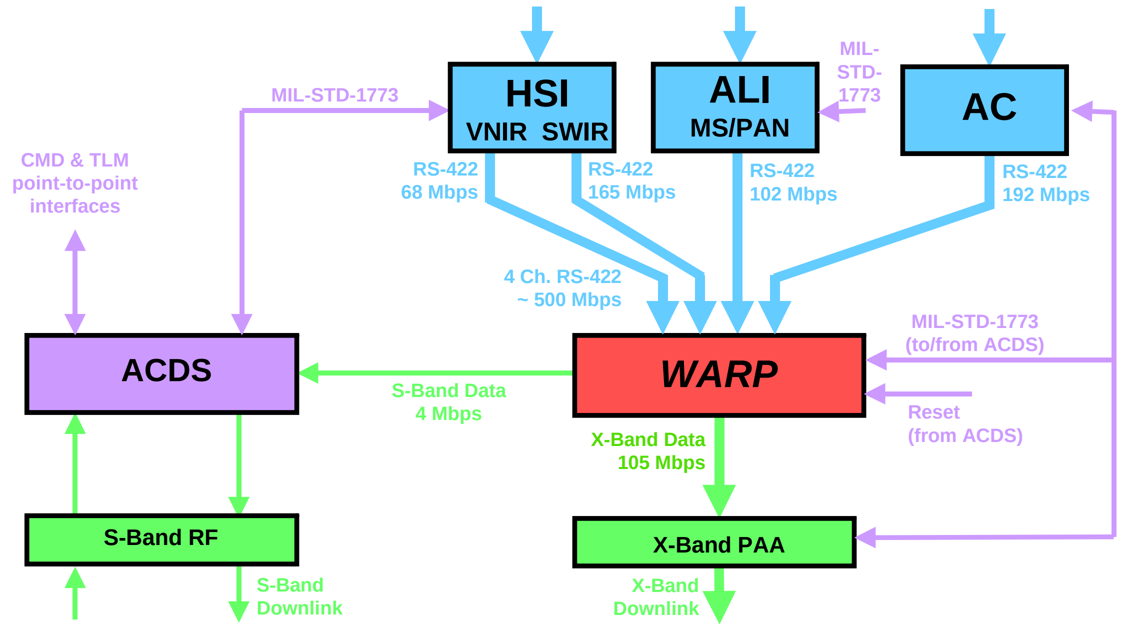
- ***Two Mongoose 5 (M5) Processors:***
  - ***C&DH, WARP***
  - ***12MHz, ~6 MIPS, 256 MB RAM on each M5***
- ***Both M5's running VxWorks 5.3.1***
- ***WARP M5 unused except for collection, S-band downlink events***
- ***WARP M5 has access to spacecraft bus for telemetry, commanding***

Earth Observing-1

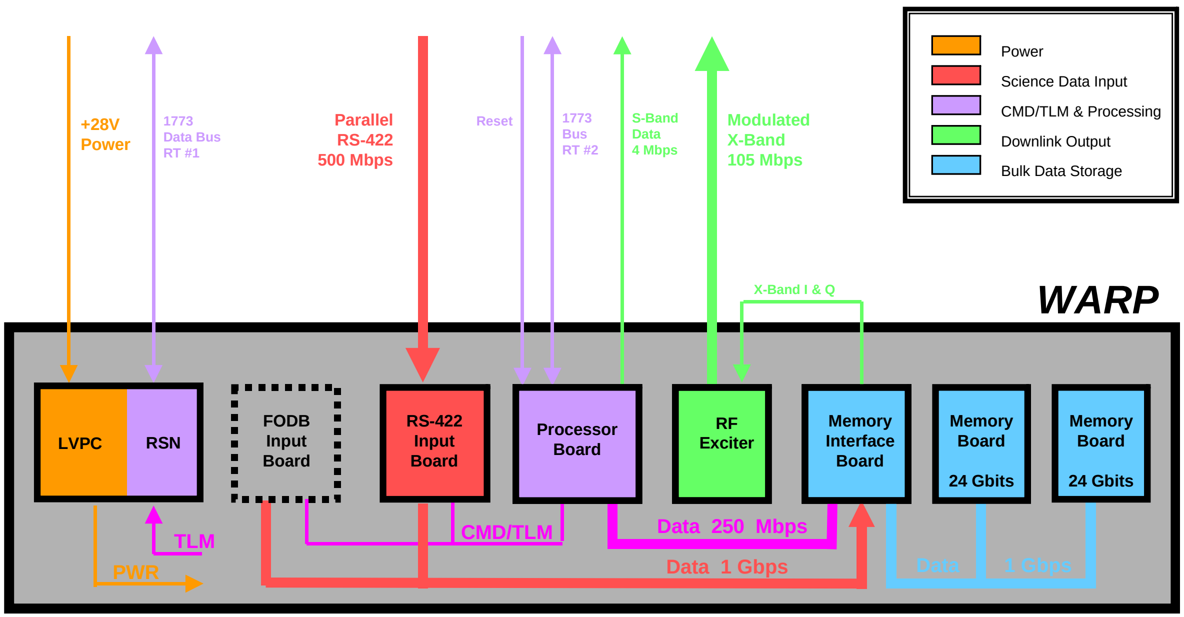
Dev Effort: EO-1 Data Architecture



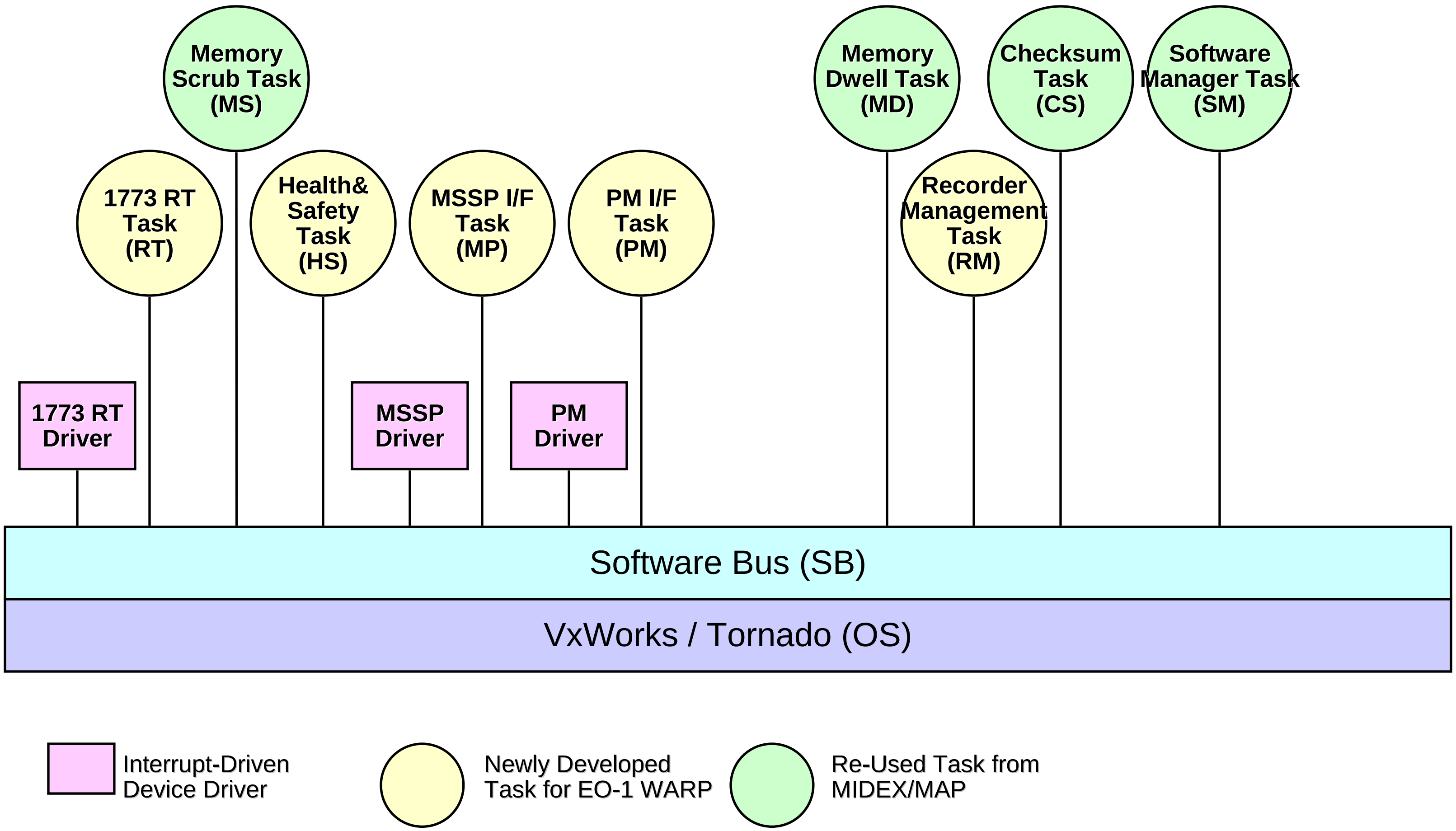
Dev Effort: WARP Data Flow



Dev Effort: WARP Block Diagram



Dev Effort: Existing WARP FSW Architecture



Dev Effort: Cloud Cover Patch Concept

- Will run as part of memory dwell, when not dwelling MD currently does nothing except wait for messages on the software bus
- Memory Dwell is lowest priority task except idle.
- S-Band playback control flow messages will be re-routed to and from the MP task to the MD task by patching the software bus routing tables.
- CC Code will run whenever data ready message is sent from RM
- MD will utilize all spare CPU in system
- Health and safety CPU hogging check will be patched out with NOPs

Dev Effort: Cloud Cover Detection Software Memory Usage

- ***Cloud cover SW patches fit between tasks (Gaps ~100kBytes)***

Data Value	***Data Type***	***Size***
Warp File IDs	*ground uplink*	*8 bytes*
Solar Zenith Angle & Julian Day	*ground uplink*	*24 bytes*
*Dark Noise Offset values (6 bands * 256 pixels * 2 bytes)*	*calculated*	*~3 Kbytes*
*Calibration factors (6 bands * 256 pixels)*	*stored*	*~6 Kbytes*
Solar flux values (6 bands)	*stored*	*24 bytes*
S-Band data local buffer	*recorded data*	*~929k (existing buffer)*
Image level 0 data	*generated*	*8 Mbytes (for 12s image)*
Cloud Cover Test Thresholds (<10)	*stored*	*40 bytes*
Cloud Cover Statistics and Telemetry	*generated*	*< 1k bytes*

Dev Effort: SW Test Approach

- ***Algorithms were integrated and tested first on a PC based simulation system using files for input test data - 9/02***
- ***Patch test – 8/02***
  - *Prove that we can patch the WARP Mongoose V without a full fidelity test bed*
  - *Patched No-op*
- ***Level 0 bandstripping test – 11/02, 12/02 and 1/03***
  - *Test of full kernel load needed for later loading of CASPER*
  - *Test capture of playback data from WARP to Mongoose*
  - *Test level 0 bandstripping of data*
- ***Level 1 and onboard cloud assessment 3/10/03***
  - *Test conversion to level 1*
  - *Test cloud algorithm*
  - *Measure performance*

Dev Effort: Development Challenges

- ***WARP test bed limitations***
  - *WARP Wide Band Recorder and associated interfaces do not exist*
  - *WARP M5 Available Memory limited to 32 Mbytes versus the onboard memory which has 256 Mbytes*
- ***Revised load process and checksum process***

Cloud Cover Estimation Procedure

- ***From calibrated Hyperion radiance data, convert to top-of atmosphere (TOA) reflectance and estimate on a pixel-by-pixel basis the extent of cloud cover in a scene.***

1. ***Convert radiance data to TOA reflectance***

   Use pre-computed band solar flux values, earth-sun distance ratio, and the solar zenith angle

2. ***Process each frame (or line) of data***

   Determine which pixels are cloud-covered

   Distinguish land, water, snow or ice from clouds

3. ***Produce cloud cover statistics for the scene***

Earth Observing-1

1. Radiance to TOA Reflectance

- Procedure -

- ***Obtain calibrated level 1B radiance data***
  - *Large part of cloud cover effort is focused on this task*
  - *1 frame (256 samples by 6 bands) at a time*
- ***Obtain from telemetry or other means for the Hyperion scene***
  - *Earth-sun distance ratio* d_{e-s}
  - *Cosine of the solar zenith angle* μ_0
  - *Band Solar Flux values* $S_{0,i}$
- ***For each band* i *use the following formula to convert the calibrated Hyperion radiance* L_i *to reflectance* ρ_i**
- ***Final product is one TOA reflectance value for each band at each pixel***
  - $\rho(256,6)$ *for a single Hyperion frame*

$$\rho_i = \left[\frac{\pi}{\mu_0 \, S_{0,i} / d_{e-s}^2} \right] L_i$$

2. Cloud Cover Algorithm
- Basic Tests -

- ***The cloud cover algorithm uses only 6 bands of Hyperion data***
  - ***0.56, 0.66, 0.86, 1.25, 1.38, 1.65 μm***

0.56 μm : used w/ 1.65 μm to compute the snow index

0.66 μm : basic cloud reflectance test channel

0.86 μm : used w/ 0.66 μm in NDVI-like ratio test

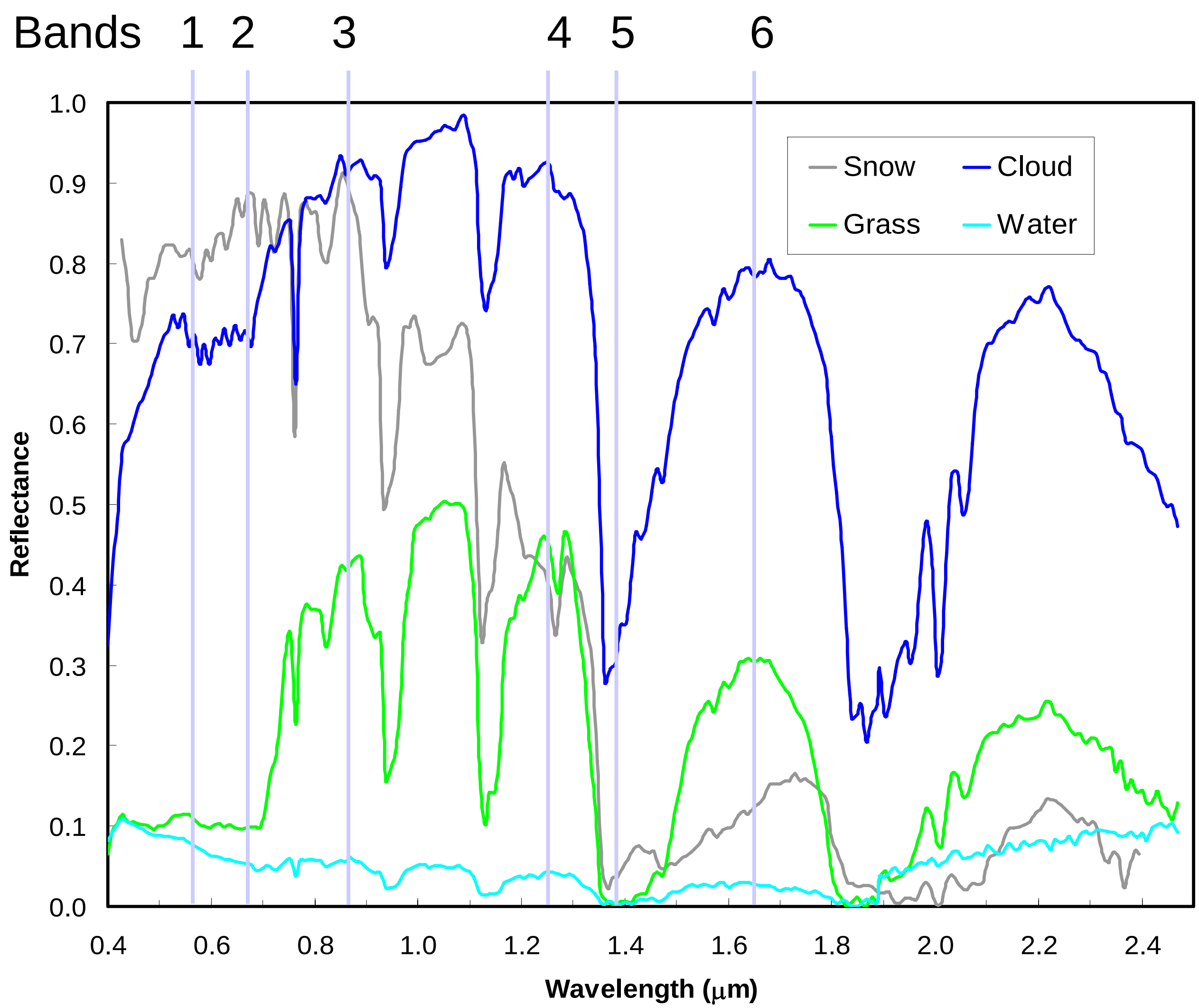
1.25 μm : desert/sand discrimination

1.38 μm : high cloud test channel

1.65 μm : used w/ 0.56 μm to compute the snow index

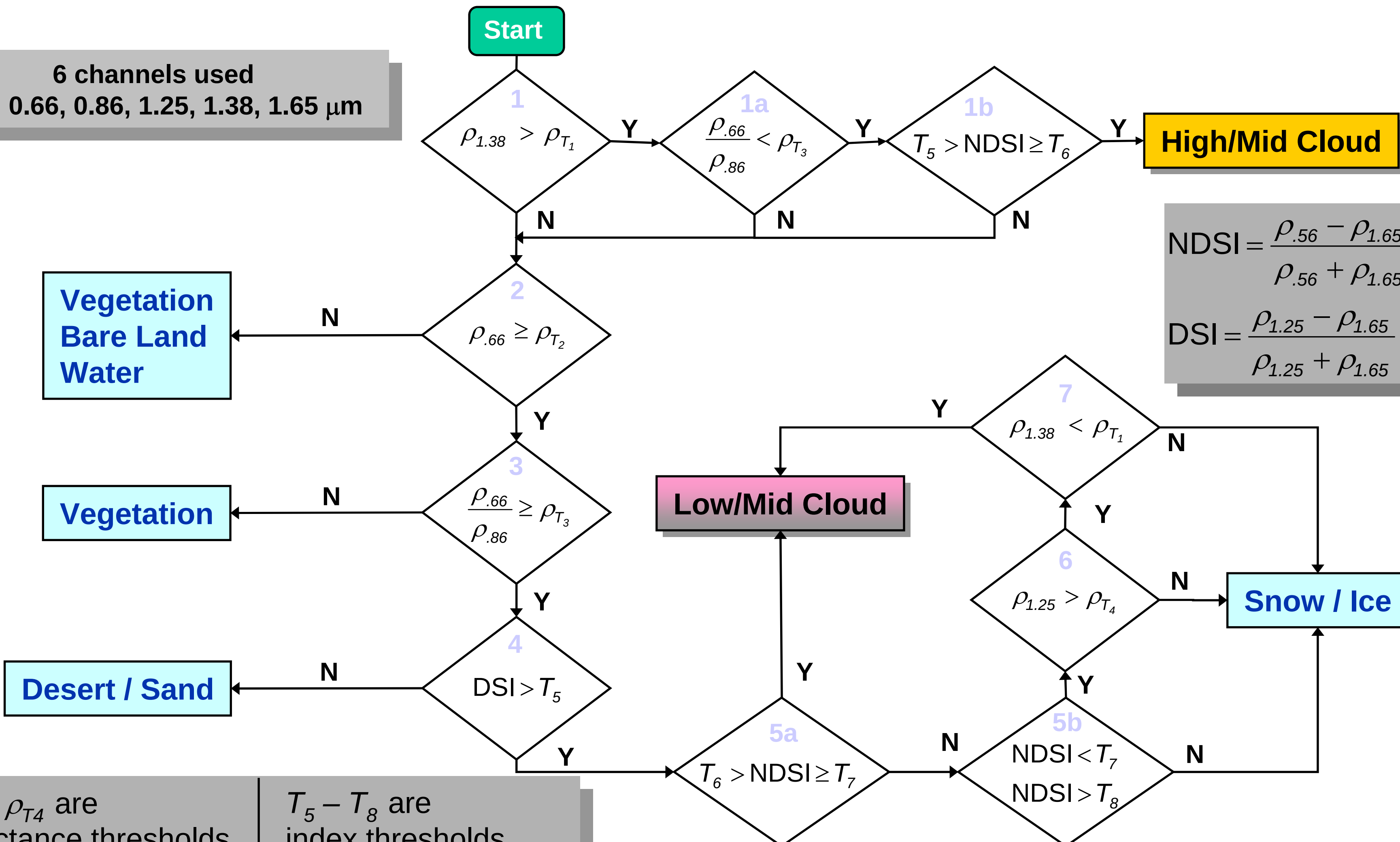
- ***On-board processing limitations requires small number of bands***
- ***Each test utilizes TOA reflectance data***
- ***20 Hyperion scenes of varying surface and cloud features were used to define test thresholds***

Spectral Band Locations With Sample Reflectance Curves



Cloud Cover Detection Algorithm

6 channels used
0.56, 0.66, 0.86, 1.25, 1.38, 1.65 µm



$$\text{NDSI} = \frac{\rho_{.56} - \rho_{1.65}}{\rho_{.56} + \rho_{1.65}}$$

$$\text{DSI} = \frac{\rho_{1.25} - \rho_{1.65}}{\rho_{1.25} + \rho_{1.65}}$$

$\rho_{T1} - \rho_{T4}$ are reflectance thresholds	$T_5 - T_8$ are index thresholds

NDSI: Normalized Difference Snow Index, DSI: Desert/Sand Index

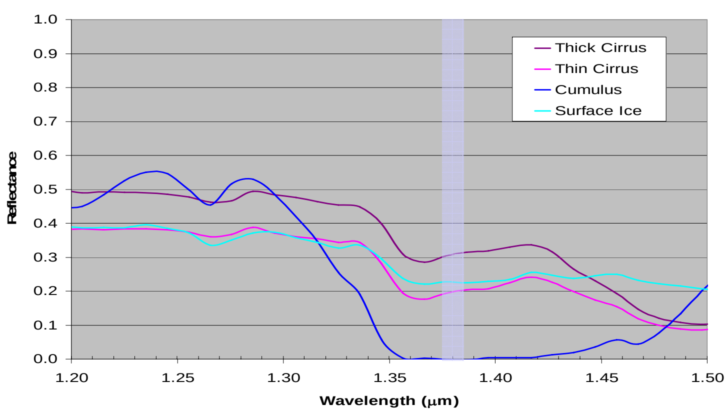
Earth Observing-1

Cloud Cover Algorithm
- NIR Absorption Band Tests -

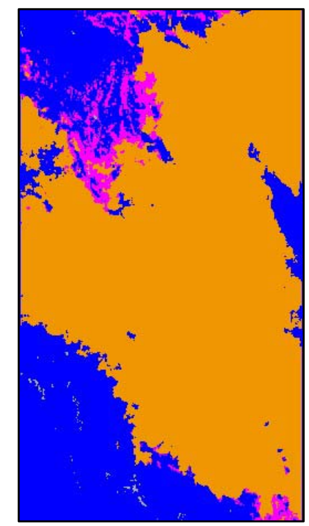
Test 1 : High/mid cloud reflectance threshold

$$\rho_{1.38\,\mu m} > \sim 0.1$$

- *Only high clouds are typically observed in this channel*
- *Strong water vapor absorption masks most low level/surface features*
- *Under dry conditions, surface features such as ice and snow can be observed and mistaken for clouds*
- *Further vegetation and snow/ice discrimination tests are necessary to isolate clouds*



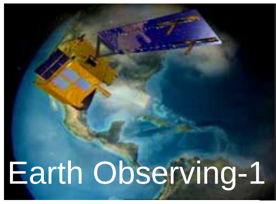
Cheyenne Wyoming



Cloud-free, Low/Mid cloud, Mid/High cloud

No (N)	***Yes (Y)***
All others	***High/Mid Clouds***

To Test 2

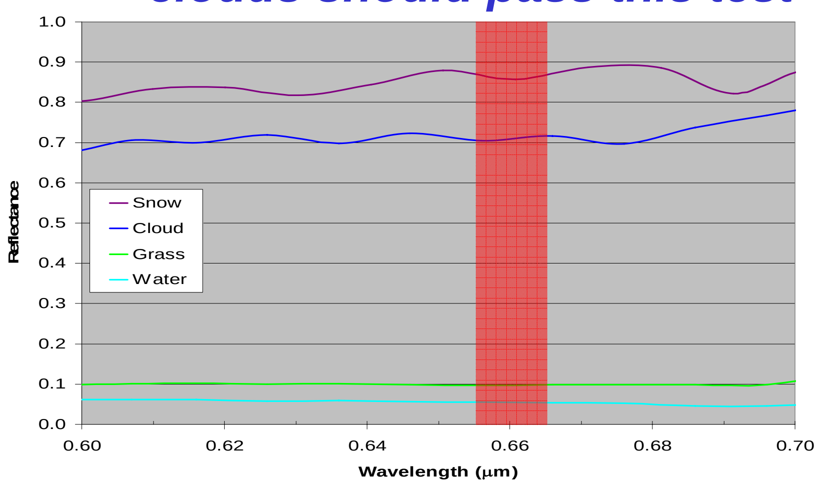


2. Cloud Cover Algorithm
- Visible Reflectance Test -

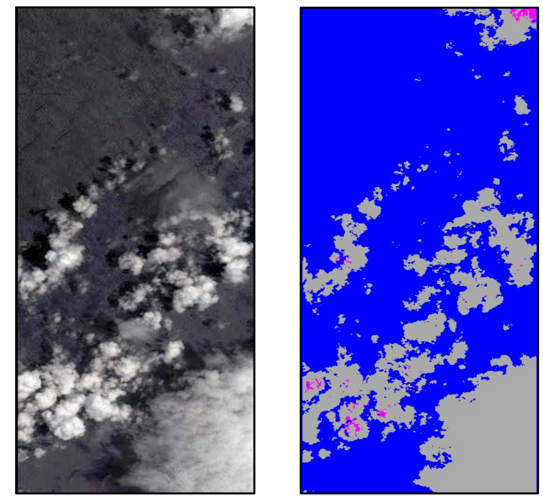
Test 2 : Red channel reflectance threshold

$$\rho_{0.66\ \mu m} > \sim 0.3$$

- *Assumes low reflectance of most vegetation, soil and water surfaces in the red region of the spectrum*
- *Snow, Ice, bright desert/sand surfaces and clouds should pass this test*



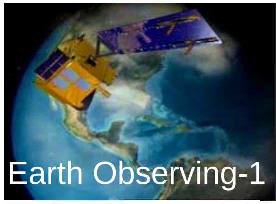
Kokee Hawaii



Cloud-free **Low/Mid cloud**

No (N)	Yes (Y)
Vegetation	*Snow / Ice*
Soil	*Desert / Sand*
Water	*Some Vegetation*
	Clouds

To Test 3



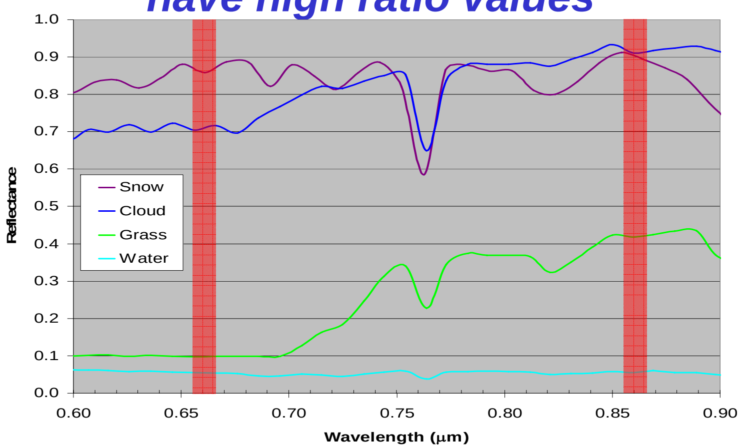
2. Cloud Cover Algorithm
- Visible/NIR Ratio Test -

Test 3 : VIS/NIR ratio test

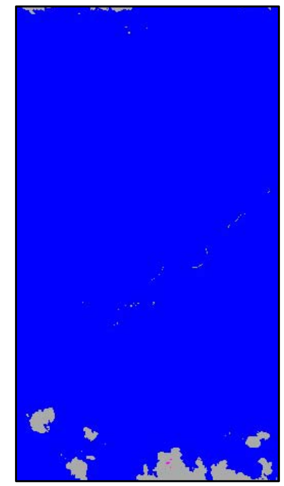
Kokee Hawaii

$$\rho_{0.66\ \mu m} / \rho_{0.86\ \mu m} > \sim 0.7$$

- *Discriminates vegetative surfaces whose reflectance varies strongly from Visible to NIR*
- *Vegetative and soil surfaces exhibit small ratio values.*
- *Clouds, desert/sand, snow and ice surfaces have high ratio values*



Cloud-free



Low/Mid cloud

No (N)	*Yes (Y)*
Vegetation	*Snow / Ice* *Desert / Sand* *Clouds*

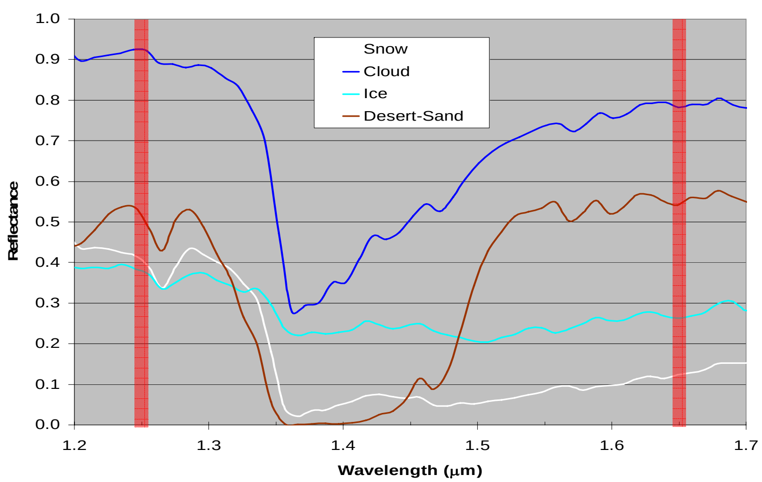
To Test 4

2. Cloud Cover Algorithm
- Bright Desert/Sand -

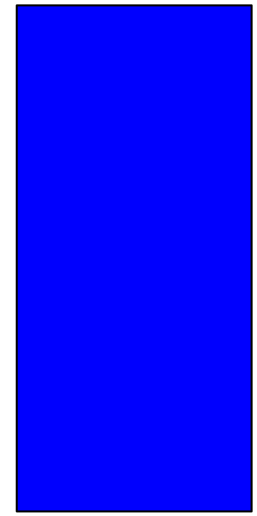
Test 4 : Desert Sand Index (DSI)

$$\mathrm{DSI} = \frac{\rho_{1.25} - \rho_{1.65}}{\rho_{1.25} + \rho_{1.65}} > -0.01$$

- ***Discriminates bright soil and sand surfaces whose reflectance increases slightly from 1.25 to 1.65 μm***
- ***Clouds, snow and ice reflectance tends to decrease over this range***



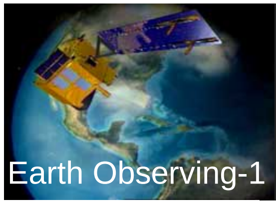
Suez Canal



Cloud-free

No (N)	*Yes (Y)*
Desert Sand Bright Soil	***Snow / Ice Clouds***

To Test 5

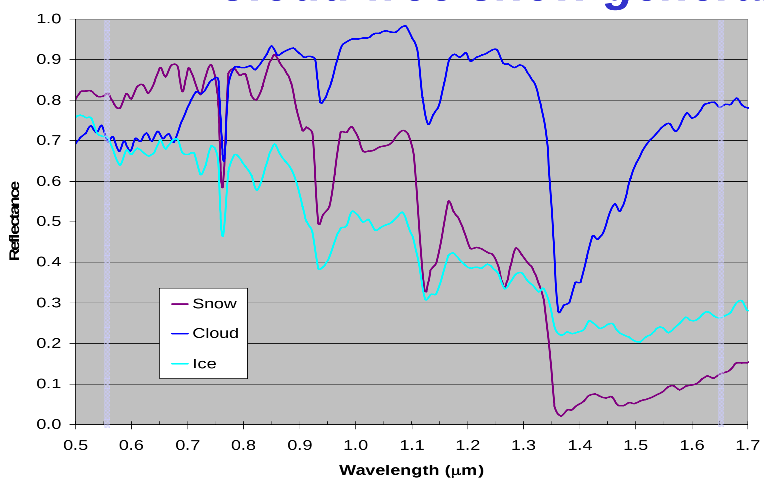


Cloud Cover Algorithm
- SWIR Snow/ice/cloud Test -

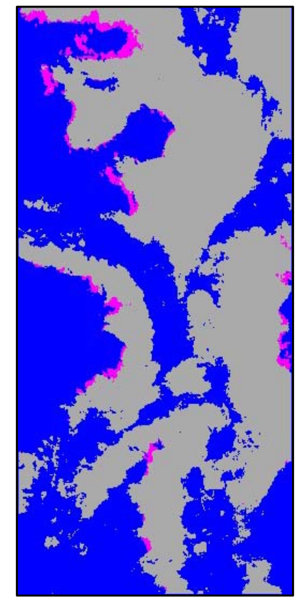
Test 5 : Normalized Difference Snow Index (NDSI)

$$\mathrm{NDSI} = \frac{\rho_{0.56\,\mu m} - \rho_{1.65\,\mu m}}{\rho_{0.56\,\mu m} + \rho_{1.65\,\mu m}}$$

- ***Some sparse or shadowed snow (in mountains) can pass test***
- ***Cloud-free snow generally displays***



Sullivan Bay



Cloud-free **Low/Mid cloud**

No (N)	Yes (Y)
Snow / Ice	***Low / Mid Clouds*** ***Dark Snow***

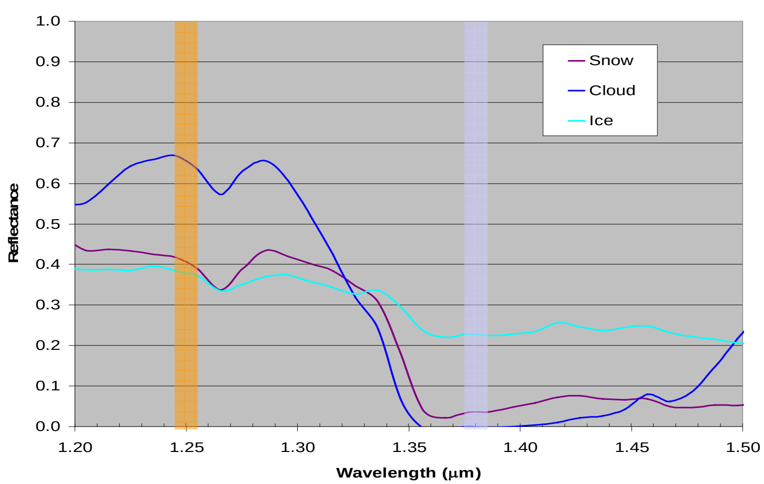
To Test 6

Cloud Cover Algorithm
- SWIR Reflectance Tests -

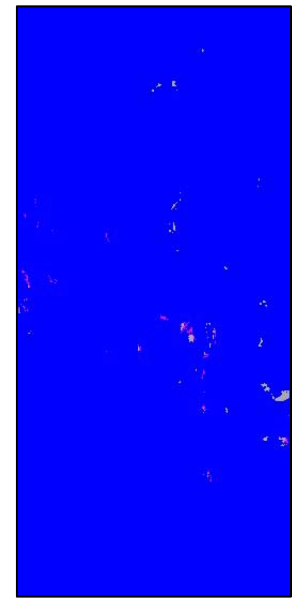
SWIR Reflectance Tests

Bering Sea

- ***Test 6*** $\rho_{1.25\ \mu m} > \sim 0.35$
- ***Test 7*** $\rho_{1.38\ \mu m} < \sim 0.1$
- ***Eliminates most snow/ice***
- ***Low/Mid clouds should pass tests***



Cloud-free



Low/Mid cloud

No (N)	***Yes (Y)***
Snow / Ice	***Low / Mid Clouds***

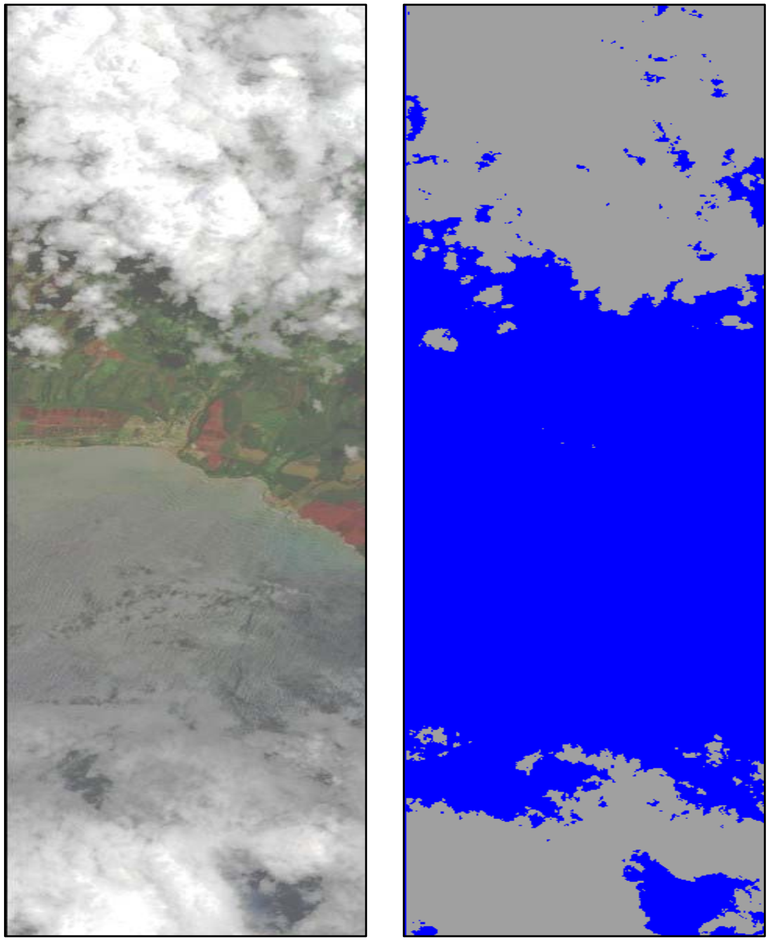
Cloud Cover Algorithm
- Test Case Results -

- ***The following slides show results from the cloud cover algorithm for a selection of Hyperion scenes***
- ***One or two segments (1000 lines each) of the overall Hyperion scene are displayed***
- ***Cloud cover estimates (percent of displayed scene covered by all clouds) is shown at the bottom***
- ***Examples are meant to highlight successes and failures of algorithm***

Colors
Cloud-free
Low/Mid cloud
Mid/High cloud

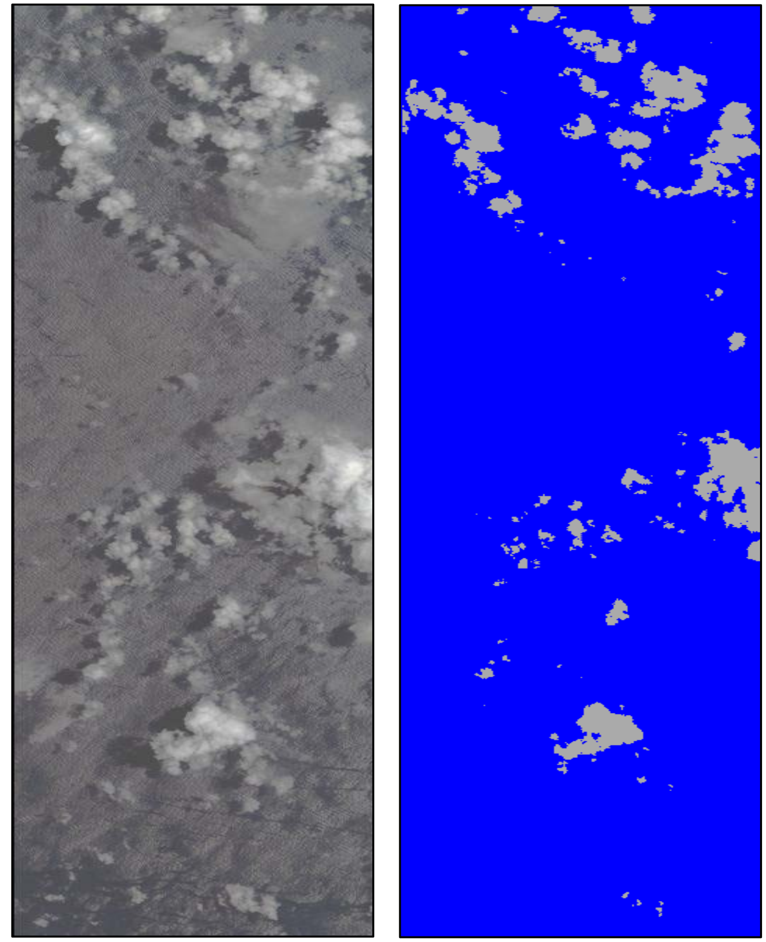
Kokee Hawaii

Lines 1700 - 2700



Total Cloud: 41.3 %

Lines 3200 - 4200

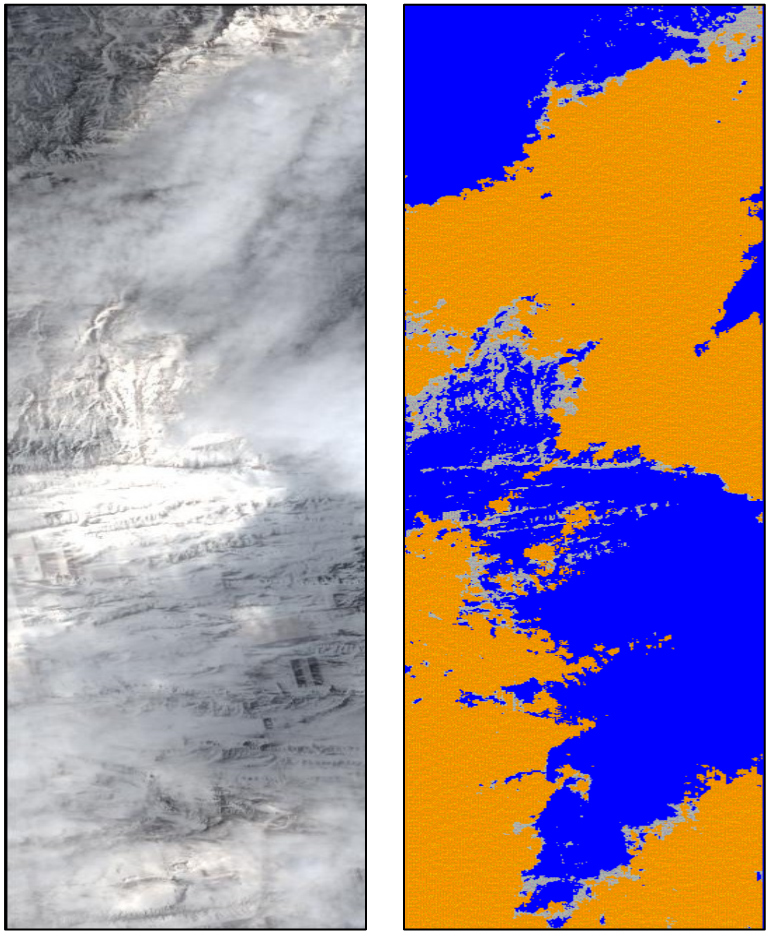


Total Cloud: 6.8 %

Success	***Discriminates land/cloud, land/water***
Failure	***Misses some darker cloud over water***

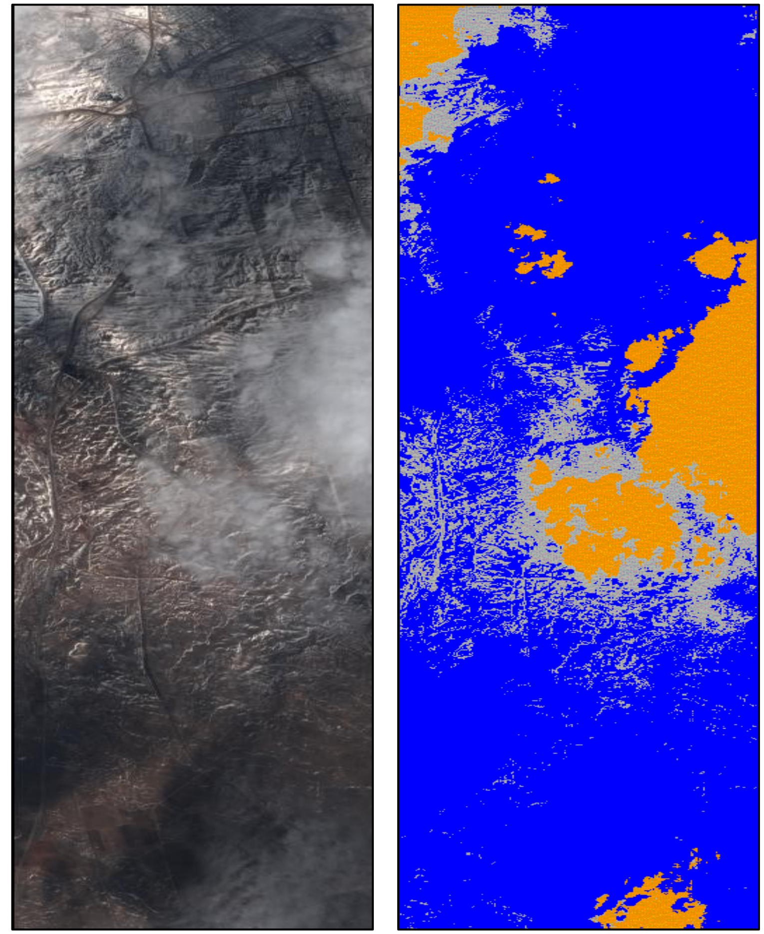
Cheyenne Wyoming

Lines 500 - 1500



Total Cloud: 58.9 %

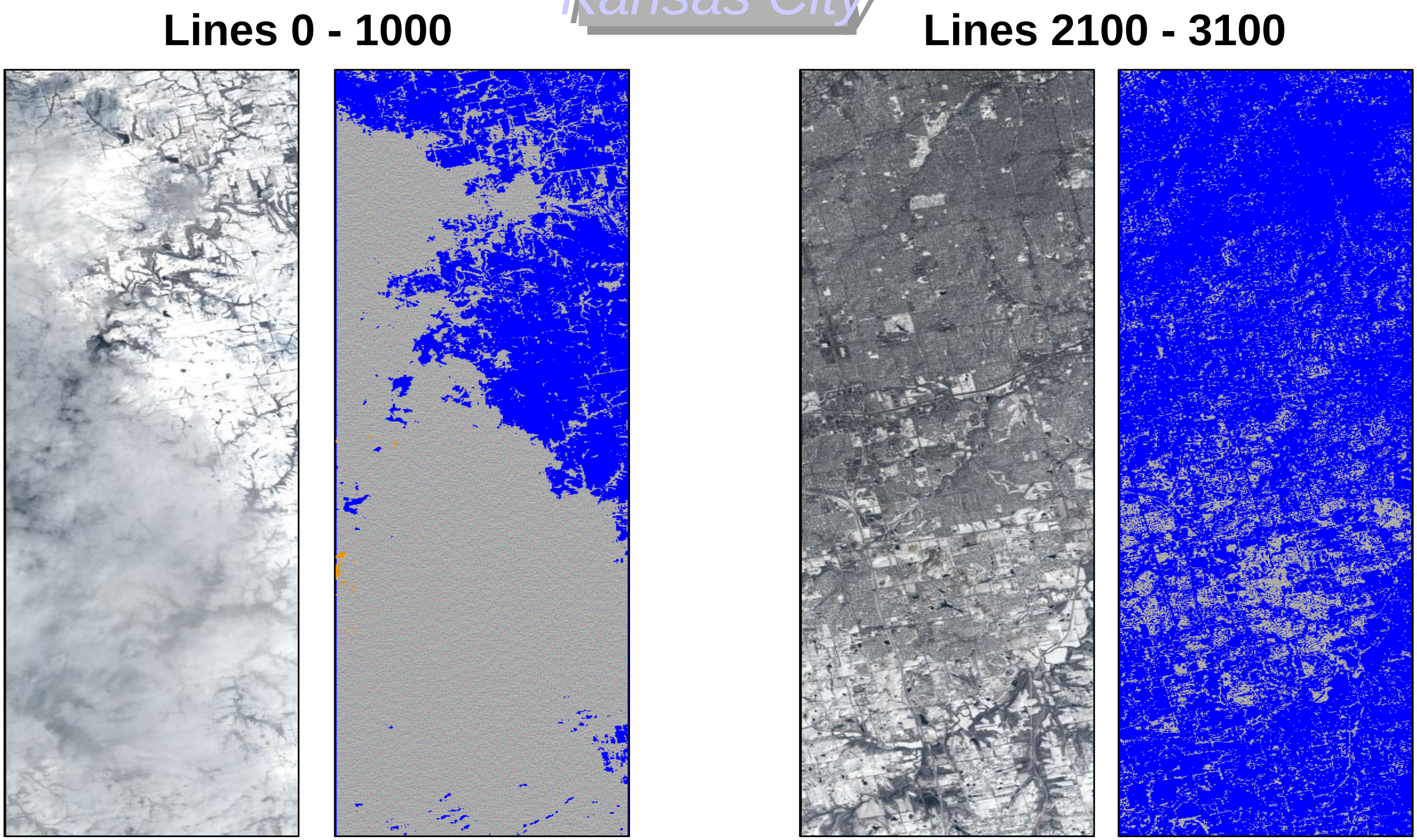
Lines 2000 - 3000



Total Cloud: 27.0 %

Success	***Snow/cloud, ice cloud***
Failure	***Difficulty with shadowed snow cover***

Kansas City

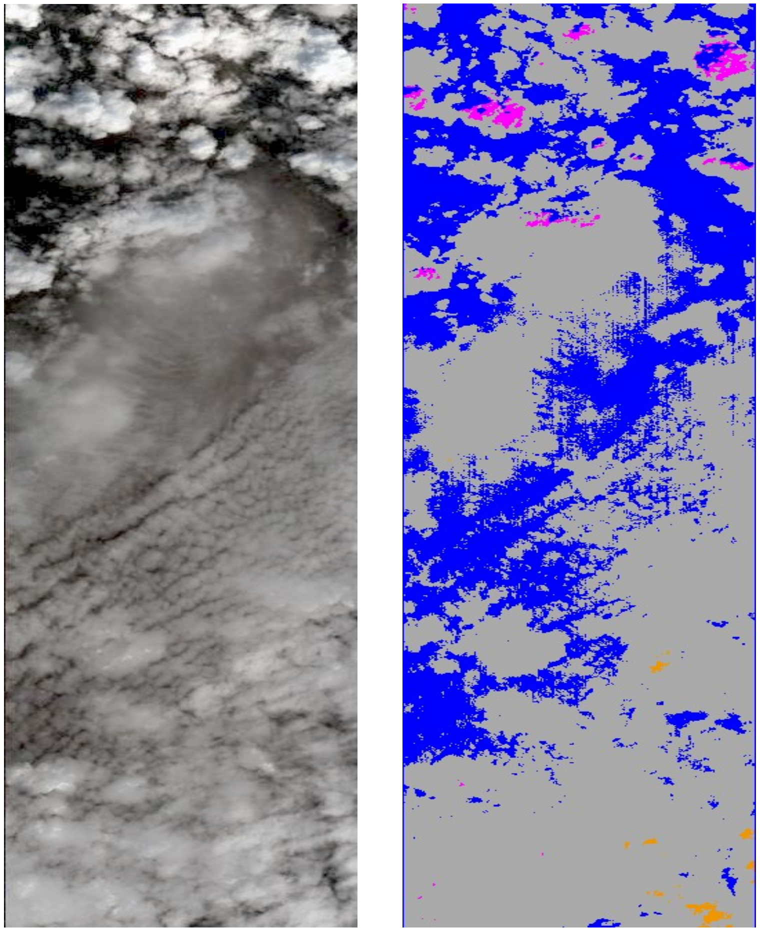


Total Cloud: 72.6 %

Total Cloud: 18.6 %

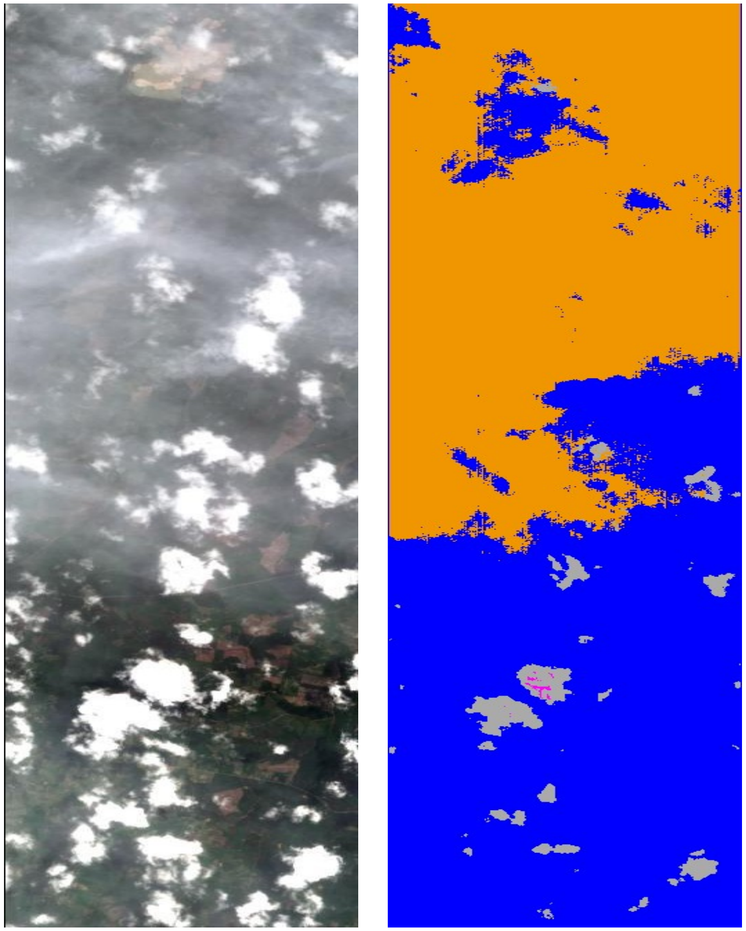
Success	***Bright Snow/cloud discrimination***
Failure	***Some snow cover flagged as cloud***

Chiefs Island



Total Cloud: 68.9 %

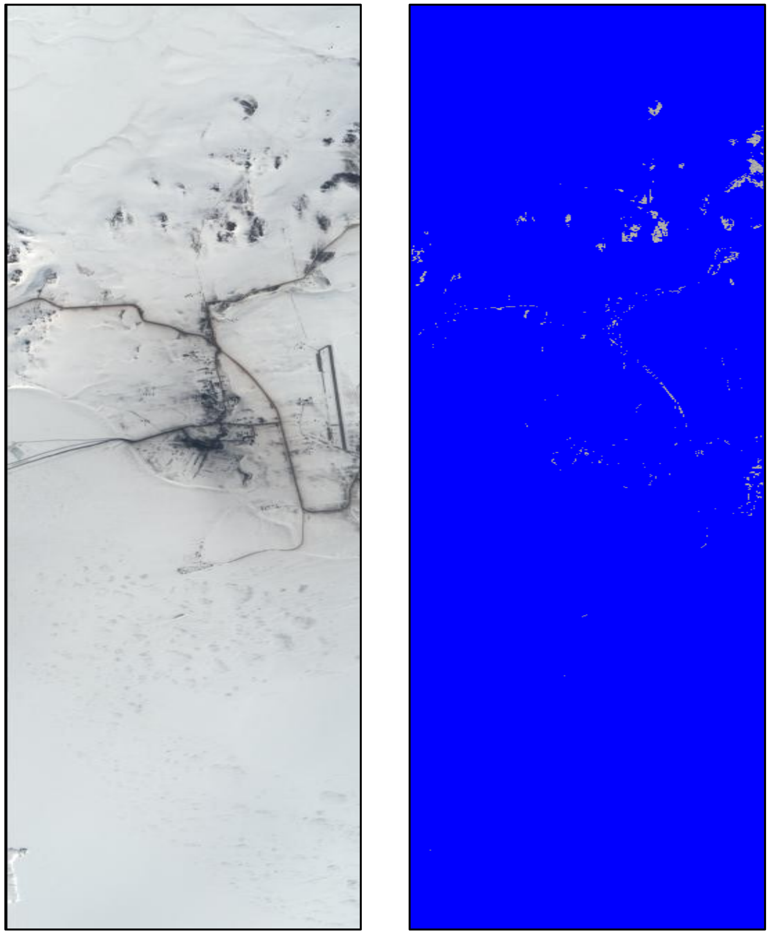
Lake Pontchartrain



Total Cloud: 48.6 %

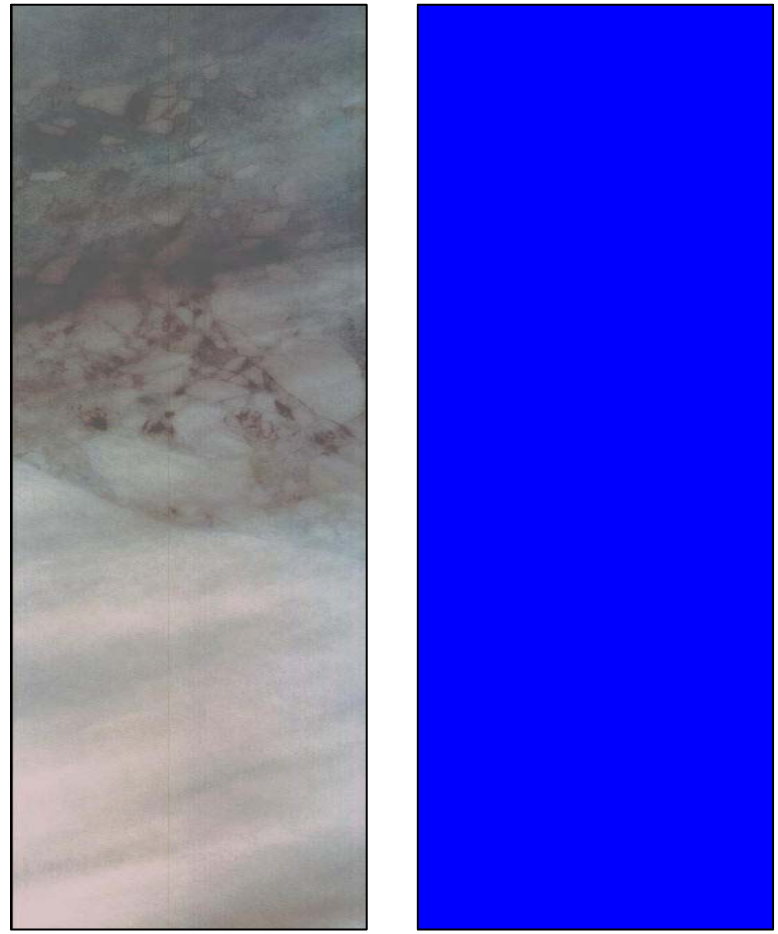
Success	***Detects Cirrus, Cumulus***
Failure	***Cloud Cover underestimated***

Bering Sea



Total Cloud: 0.7 %

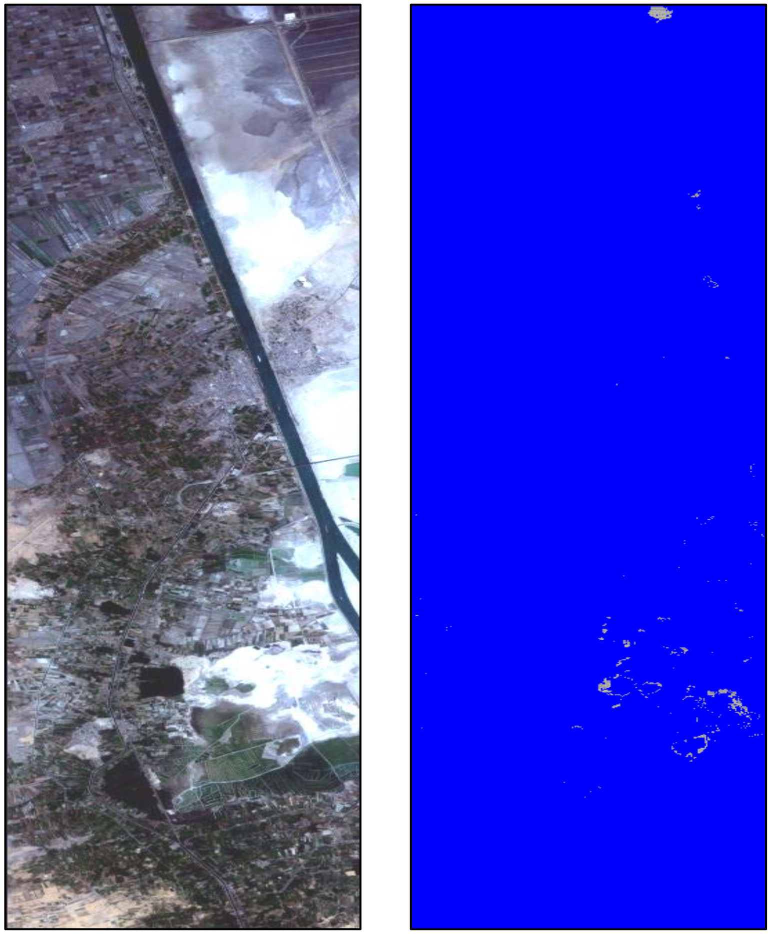
Larsen Ice Shelf



Total Cloud: 0.0 %

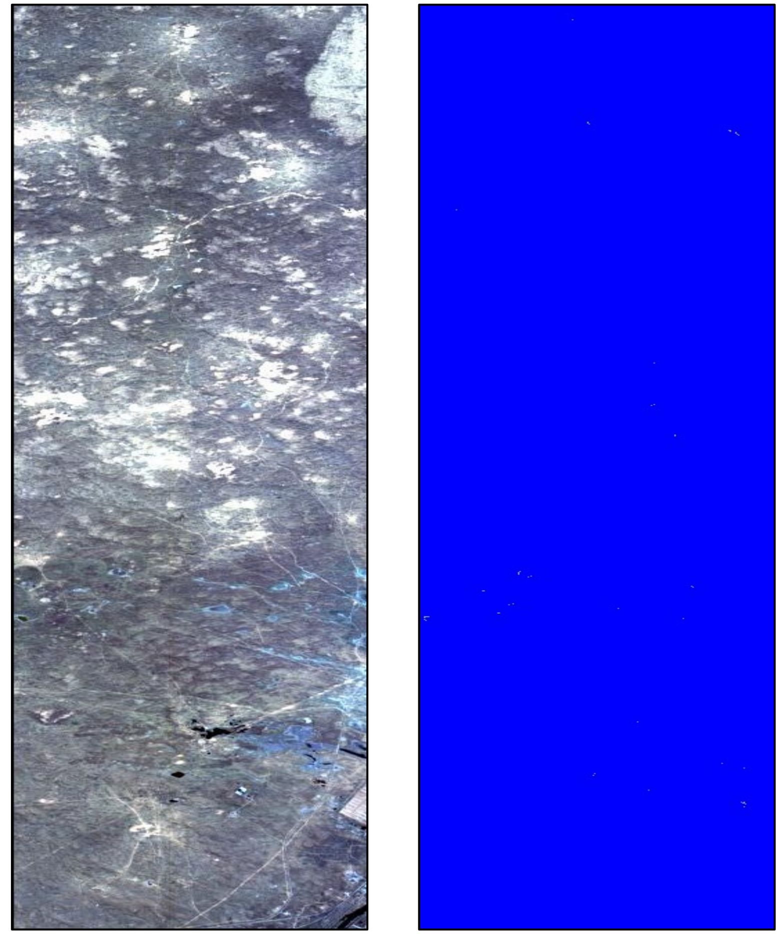
Success	***Bright Ice, snow all flagged clear***
Failure	***Small amount of dark snow features***

Suez Canal



Total Cloud: 0.3 %

Chernobyl



Total Cloud: 0.0 %

Success	*Bright sand, soil all flagged clear*
Failure	*Small amount of bright soil*

Summary of Cloud Cover Algorithm Performance

Schedule calls for first on-board test in December 2002

- ***Algorithm results are encouraging***
- ***On-board cloud cover detection accuracy requirements are not stringent (10-15 %)***
  - *Only need to know if scene is clear enough for user*
  - *Simple algorithms with limited # of bands sufficient*
- ***Algorithm does a good job not classifying bright surface features (snow, ice, sand) as clouds***
- ***Difficulties with dark snow and dark/shadowed features***
  - *Adjustment of thresholds (e.g., geographical, seasonal) may improve results*
- ***Areas for future enhancements/improvements***
  - *More sophisticated algorithms*
  - *More bands*
  - *More precise validation of actual cloud cover*

Conclusion

- *Discovered many methods to streamline onboard cloud assessment*
- *Big driver to onboard cloud assessment is precision required*
  - ***For many applications, accuracy within a 5% is adequate thereby allowing shortcuts***